A Printed UWB Antenna with Full Ground Plane for WBAN Applications

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Abstract—In this paper, an ultra-wideband (UWB) antenna based on an inherently narrowband microstrip technology is proposed for wireless body area network (WBAN) applications. UWB bandwidth extending from 4 to 9.5 GHz is obtained by applying several bandwidth enhancement techniques to the radiator printed on the upper surface of a substrate. To shield the radiator from the body as much as possible, we impose a full ground plane on the lower surface of the substrate, which is not found in nearly all printed UWB antennas. A study has been conducted through simulations in both free space and close proximity to frequency-dependent homogeneous human muscle-equivalent phantoms to determine the human body's effects on the performances of the antenna. The results reveal that the antenna is robust against both human body loading and structural deformation, and has less impact on body tissues, indicating a very promising candidate for body-worn applications.

Keywords—Full ground plane, printed antenna, ultra-wideband (UWB) antenna, wearable antenna, Wireless Body Area Network (WBAN).

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Professor Karu Esselle, IEEE ‘M (1992), SM (1996), F (2016), received BSc degree in electronic and telecommunication engineering with First Class Honours from the University of Moratuwa, Sri Lanka, and MASc and PhD degrees in electrical engineering from the University of Ottawa, Canada. He is a Professor of Electronic Engineering, Macquarie University, Sydney, and the Past Associate Dean – Higher Degree Research (HDR) of the Division of Information and Communication Sciences. He has also served as a member of the Dean’s Advisory Council and the Division Executive from 2003 to 2008 and as the Head of the Department several times. He is the chair of the Board of management of Australian Antenna Measurement Facility, Deputy Director (Engineering) of the WiMed Research centre, and elected 2016 Chair of both IEEE New South Wales (NSW) Section, and IEEE NSW AP/MTT Chapter. He directs the Centre for Collaboration in

Electromagnetic and Antenna Engineering. When Professor Esselle was elected to the IEEE Antennas and Propagation Society Administrative Committee for a three year term in 2014, he became the only person residing in the Asia-Pacific Region (IEEE Region 10) to be elected to this highly competitive position over a period of at least six years (2010-2015). He was elevated to IEEE Fellow grade for his extensive contributions to resonance-based antennas, both low-gain and high-gain.

Professor Esselle has authored over 450 research publications and his papers have been cited about 3,300 times. His current Google Scholar h-index of 29 is the all-time highest among Australian antenna researchers, when Google Scholar errors are corrected. Since 2002, his research team has been involved with research grants, contracts and PhD scholarships worth over 15 million dollars. His research has been funded by many national and international organisations including Australian Research Council, Intel, US Air Force, Cisco Systems and Hewlett-Packard, and Australian and Indian governments.

Professor Esselle has been invited to serve as an international expert/ research grant assessor by several nationwide research funding bodies overseas including the Netherlands, Canada, Finland, Hong-Kong, Georgia and Chile. He has been invited by Vice-Chancellors of Australian and overseas universities to assess applications for promotion to professorial levels. He has also been invited to assess grant applications submitted to Australia's most prestigious schemes such as Australian Federation Fellowships and Australian Laureate Fellowships. He leads the Implantable Wireless Program of the WiMed Research Centre. In addition to the large number of invited conference speeches he has given, he has been an invited keynote speaker of IEEE workshops and conferences.

Professor Esselle's recent awards include the 2012 Best Published Paper Award in Electronic and Telecommunication Engineering from IESL NSW Chapter, 2011 Outstanding Branch Counsellor Award from IEEE headquarters (USA), 2009 Vice Chancellor's Award for Excellence in Higher Degree Research Supervision and 2004 Inaugural Innovation Award for best invention disclosure. His mentees have been awarded many fellowships, awards and prizes for their research achievements. Thirty one international experts who examined the theses of his recent PhD graduates ranked them in the top 5% or 10%.

Professor Esselle has provided expert assistance to more than a dozen companies including Intel, Hewlett Packard Laboratory (USA), Cisco Systems (USA), Cochlear, Optus, ResMed and Katherine-Werke (Germany). He is an Associate Editor of IEEE Access and IET Microwave, Antennas and Propagation.

Professor Esselle is the Technical Program Committee Co-Chair of ISAP 2015, APMC 2011 and TENCON 2013 and the Publicity Chair of ICEAA 2016, IWAT 2014 and APMC 2000. He is the Foundation Counsellor of IEEE Student Branch at Macquarie University, and Foundation Advisor of IEEE MTT Chapter in Macquarie University. Professor Esselle's research activities are posted in the web at http://web.science.mq.edu.au/~esselle/ .

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Outline

- Introduction
- Objective
- New antenna for UWB WBAN
- Results
- Conclusion

Introduction

What is body-centric communications?

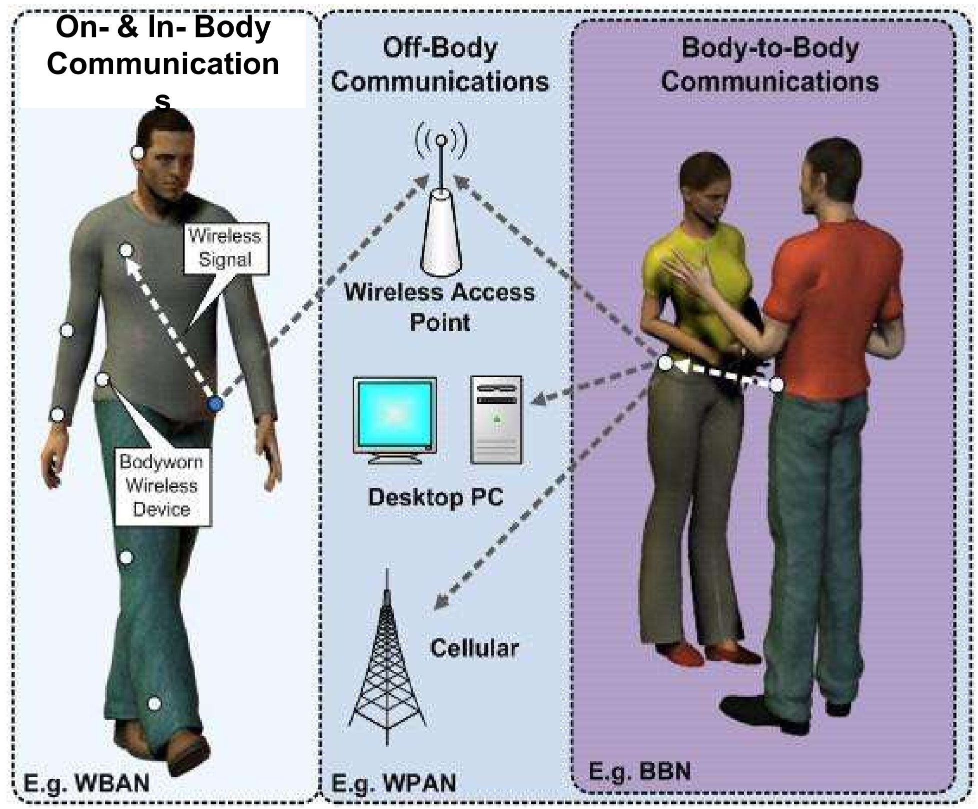
Body-centric communications:
Networking between human self and human-to-human with the use of wearable or implantable wireless devices [P. S. Hall, Y. Hao]

It combines:

Wireless Body-Area Networks (WBANs)

Wireless Sensor Networks (WSNs)

Wireless Personal Area Networks (WPAN)



Introduction

Wide range of applications

Smart textile to improve the safety and efficiency of firefighters

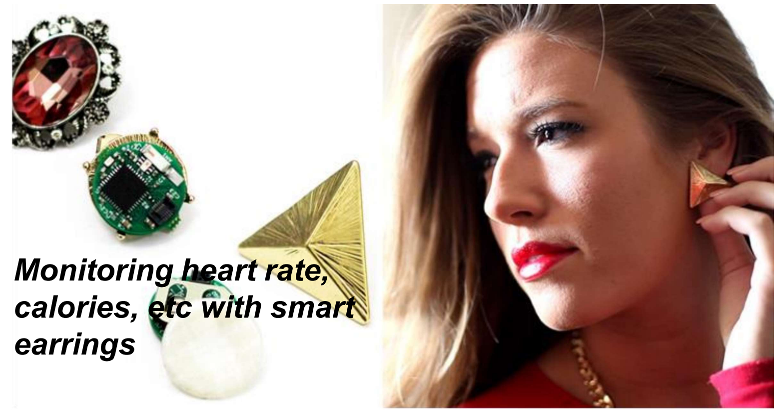
Source: www.proetex.org.

Source: www.militaryaerospace.com

Wearable computer (Dynamics Itronix GD300) used by US soldier in Afganisthan

SONY smart eye glass

Source: developer.sonymobile.com



Monitoring heart rate, calories, etc with smart earrings

Source: www.earosmart.com.

Cellular-enabled blood sugar meter: real time monitoring & update to entire circle of your care (doctors, family, etc.)

Source: www.telcare.com

Fitbit fitness partner

Source: www.fitbit.com.

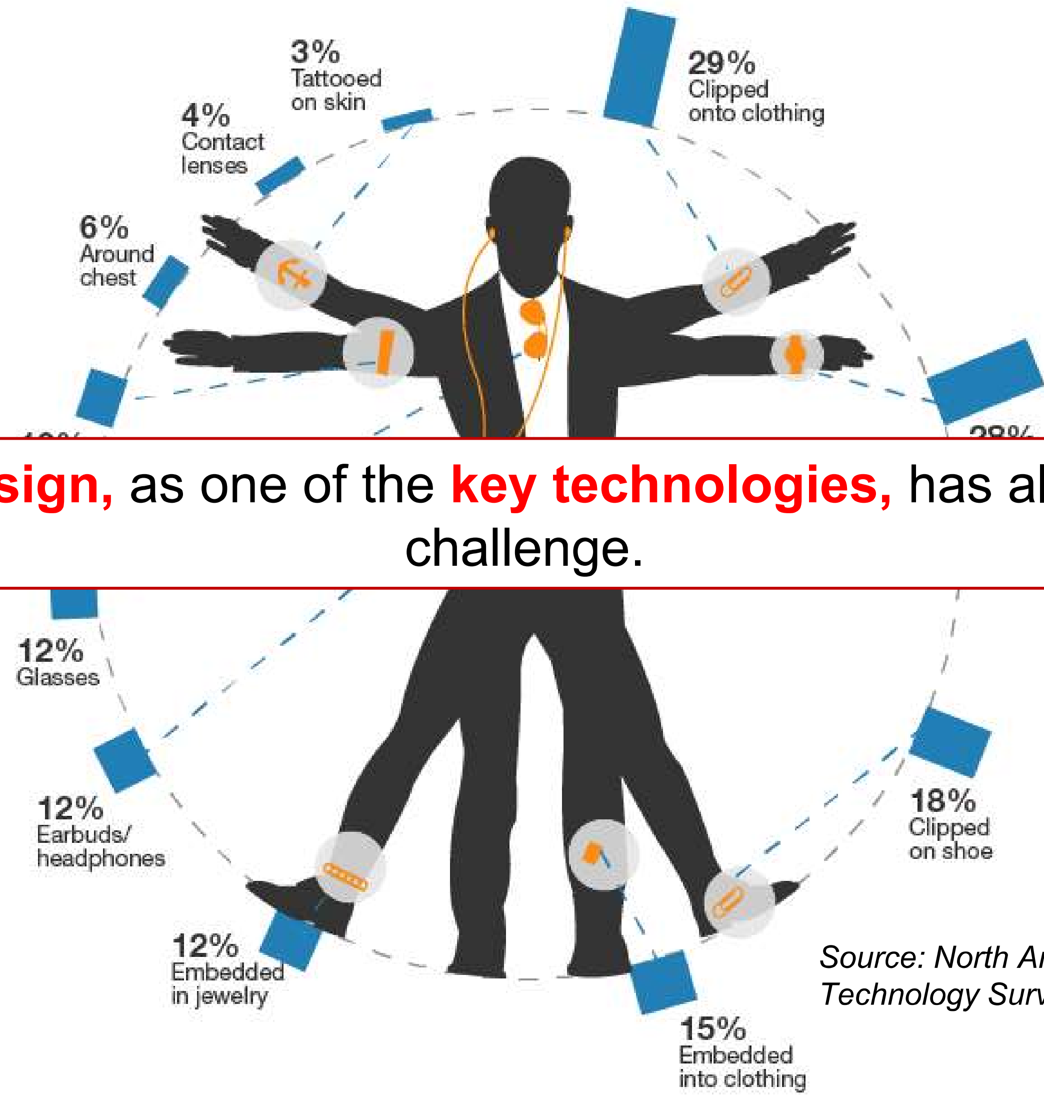
Improve running form with smart socks

Source: www.sensoriafitness.com.

Introduction

Wearable technology - revolutionary concept

Survey base: 4,657 US onine adults (18+) (multiple responses accepted)
"How would you be interested in wearing/using a sensor device, assuming it was from a brand you trust, offering a service that interests you?"



Antenna design, as one of the **key technologies,** has always been a challenge.

Source: North American Technograpichs® Consumer Technology Survey

Introduction

Antenna requirements and challenges

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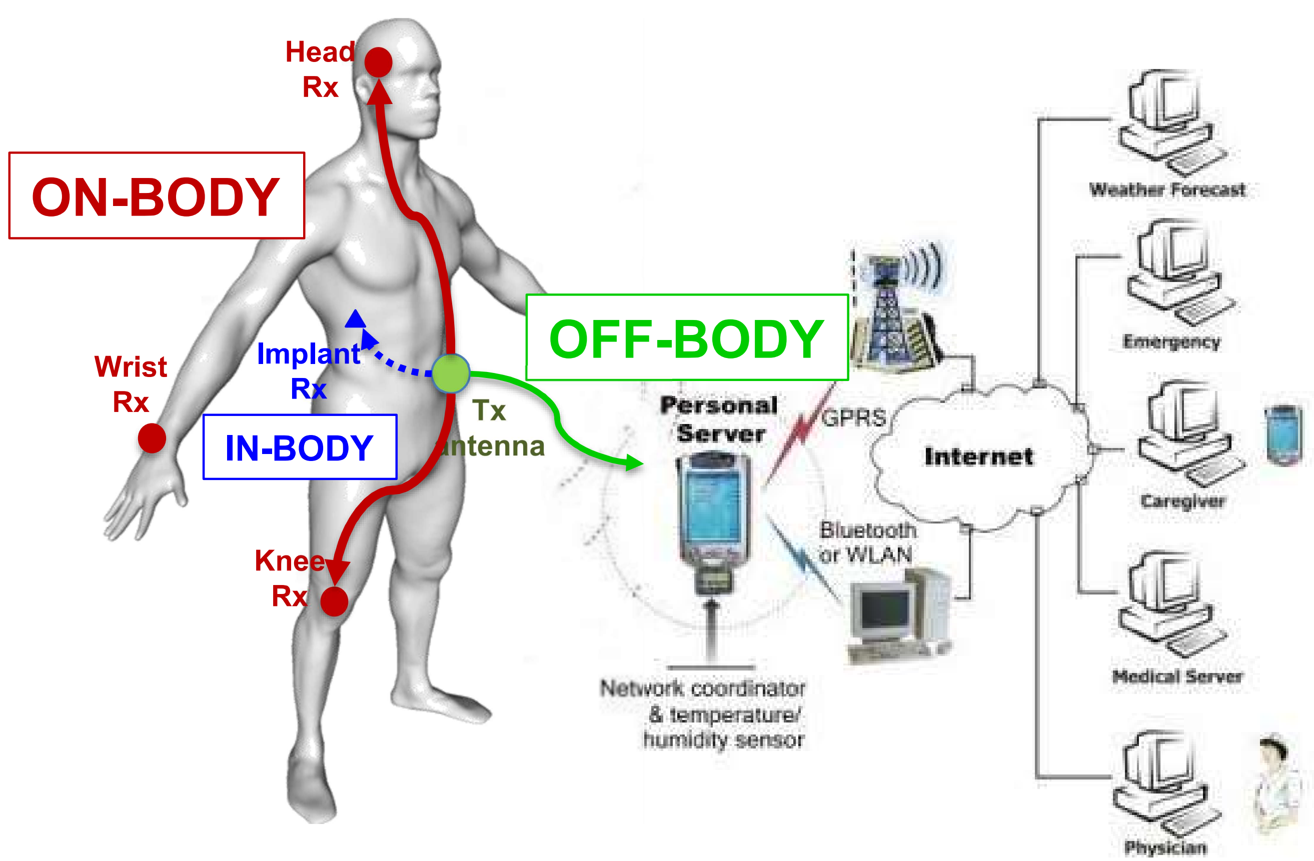
⚠ **Frequency bands:**

- Medical Implant Communications Systems (MICS) 402-405 MHz
- Industrial, Scientific, and Medical (ISM) 433.1-434.8; 902-928; 2400-2500; 5725-5875 MHz
- Ultra Wideband (UWB) 3.1-10.6 GHz
- Global System for Mobile Communications (GSM) 850/900 MHz
- Personal communications Services 1800/1900 MHz
- Wireless Local Area Network (WLAN) 2450/5000 MHz
- WiGig 60 GHz millimetre-wave?

Introduction

Antenna requirements and challenges

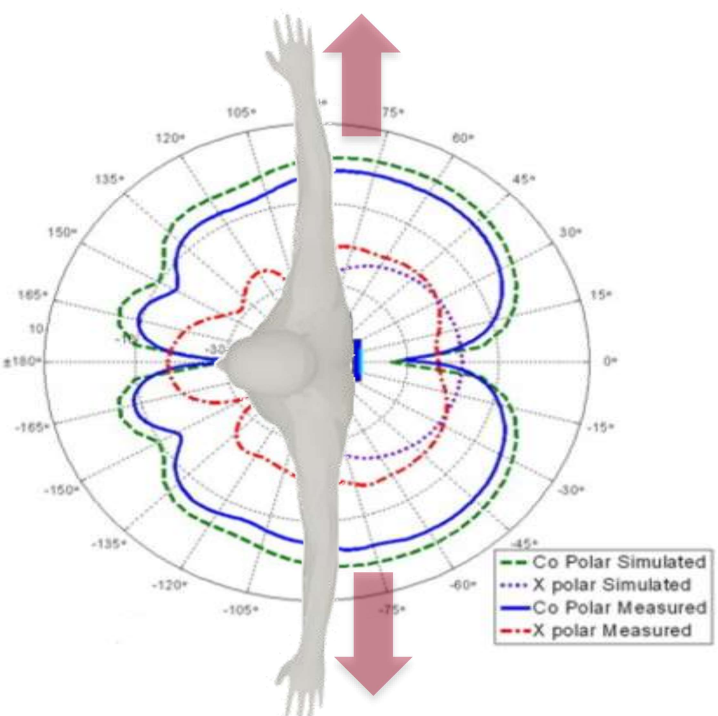
⚠ **Different radiation pattern requirements:**



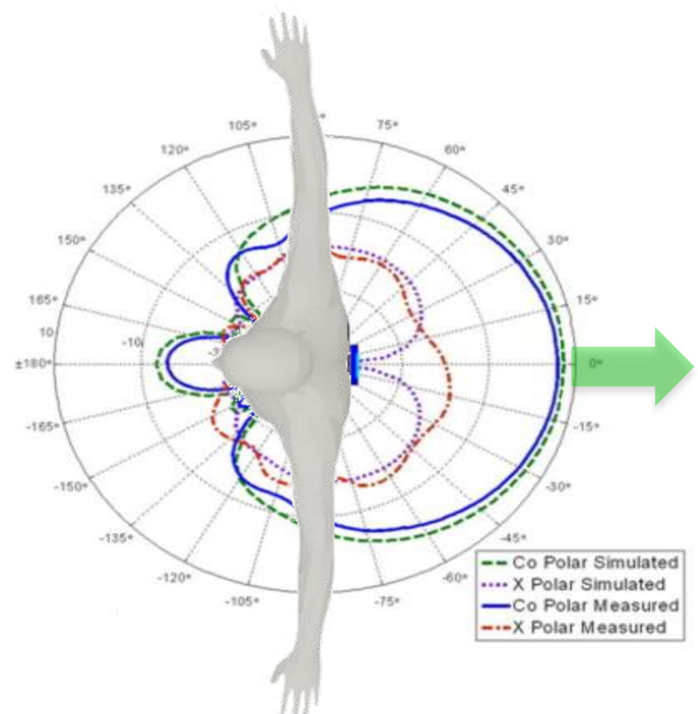
Introduction

Antenna requirements and challenges

⚠ **Radiation pattern:**



ON-BODY MODE



OFF-BODY MODE

Source: G. A. Conway & W. G. Scanlon. (2009) Antennas for over-body-surface communications at 2.45 GHz. IEEE Trans. on Antennas and Propagation, vol.57, No. 4, Apr. 2009

Introduction

Antenna requirements and challenges

⚠ **Antenna performance:**

- Input impedance, bandwidth, and radiation efficiency are robust to human body loading
- Low impact to human body tissues: Specific Absorption Rate (SAR) ↓↓

⚠ **Other desirable factors:**

Low profile; unobtrusive

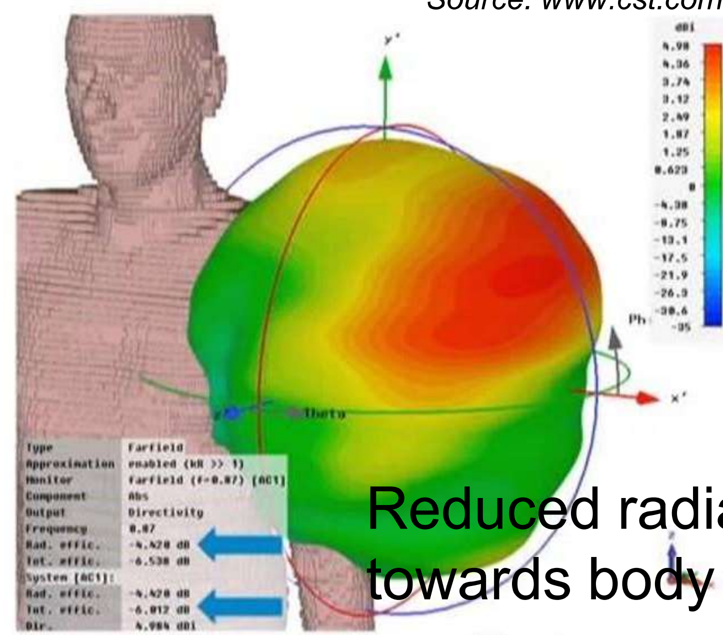
Conflicting Requirements

Solution:

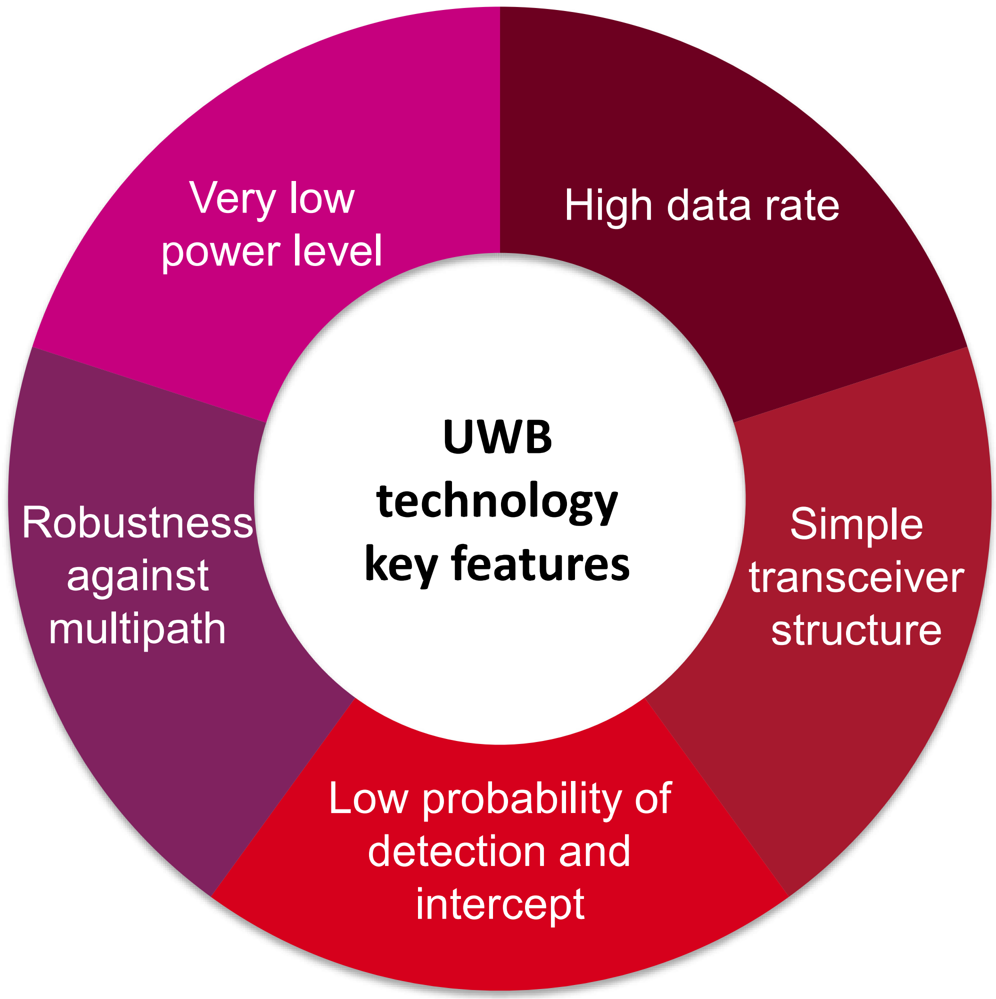
Full ground plane,

i.e. metal coating underneath the antenna to act as a partial shield between body and radiating parts of the antenna

Source: www.cst.com



Ultra wideband (UWB) technology for body-centric communications



Objective

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Printed uni-directional antennas for UWB body-centric communications

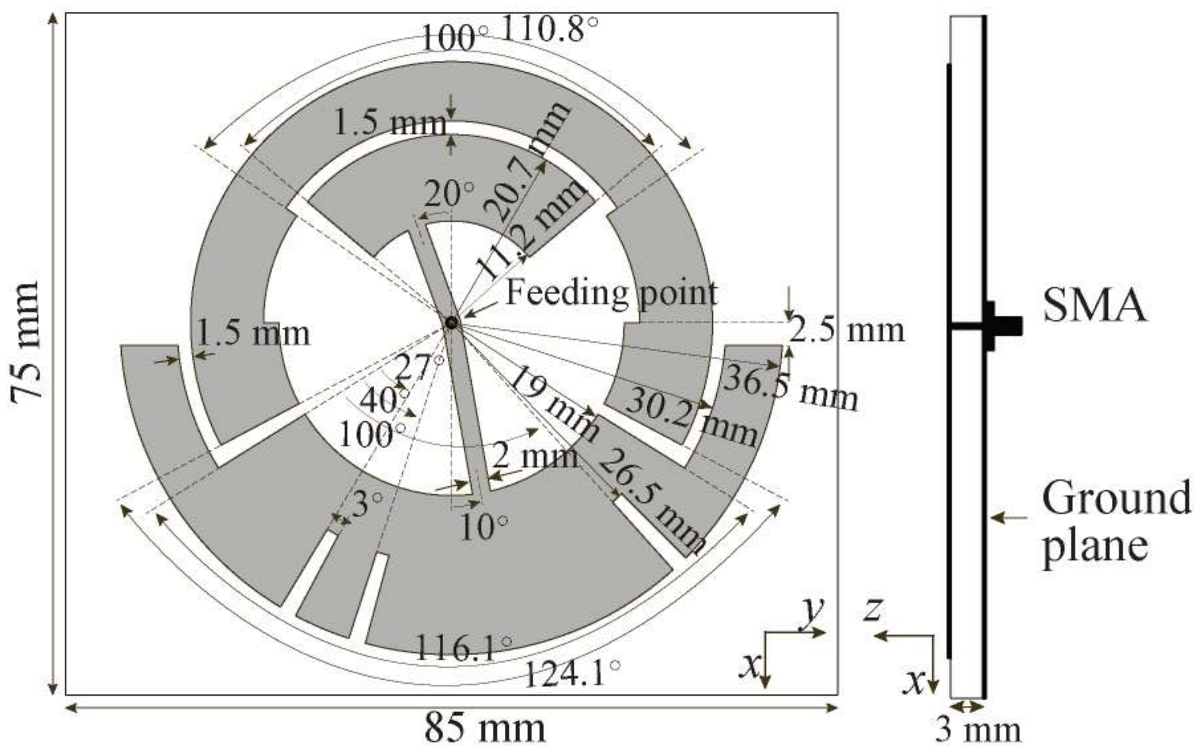
Favourable characteristics of printed antennas:
Planar structure, physical robustness, low cost, ease of manufacture, and easy to realize using flexible materials for deformability and good ergonomics.

Printed UWB antenna common problems:
Highly sensitive to the human body loading due to **the high radiation towards the backside of the antenna** (a negative effect of the **partial ground plane commonly** used for ultra wide bandwidth enhancement).

Objective:
To present a printed antenna with an **ultra wide bandwidth (FBW>25%)** and **robust characteristic against both human body loading** and **structural deformation**.

Proposed Antenna

Printed UWB antenna with full ground plane

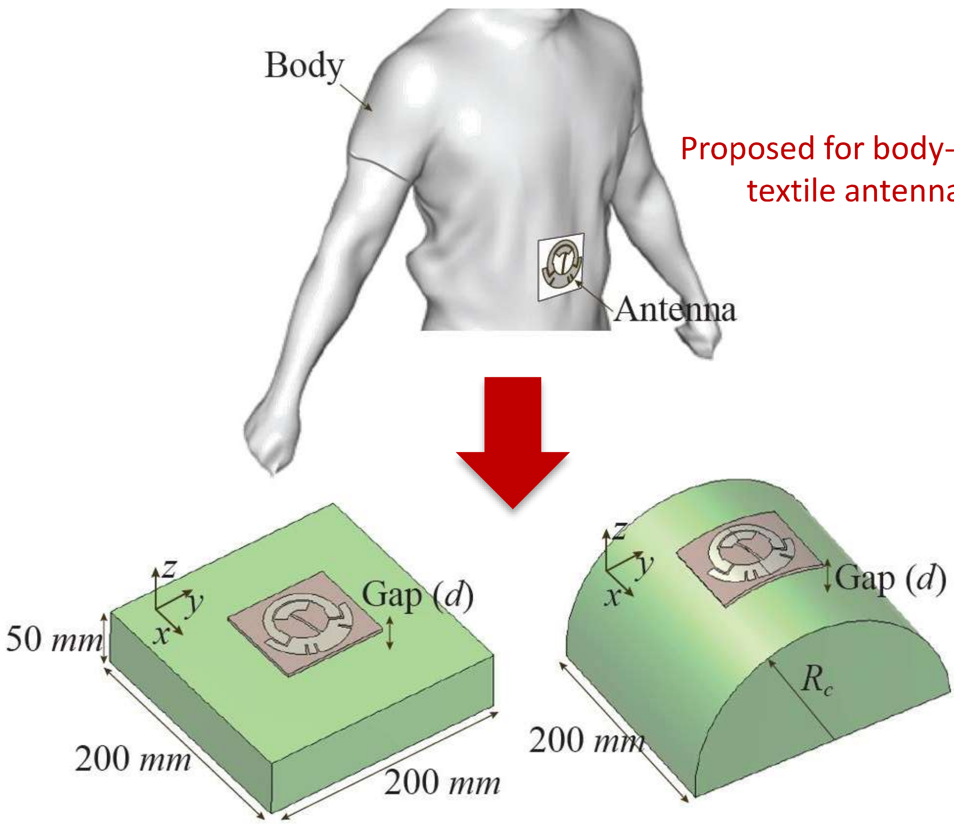


Geometry of the proposed antenna.
Top view (left) and side view (right).

Major Breakthrough:
Achieving an **ultra wide bandwidth** in an **inherently narrowband microstrip antenna** technology

Proposed Antenna

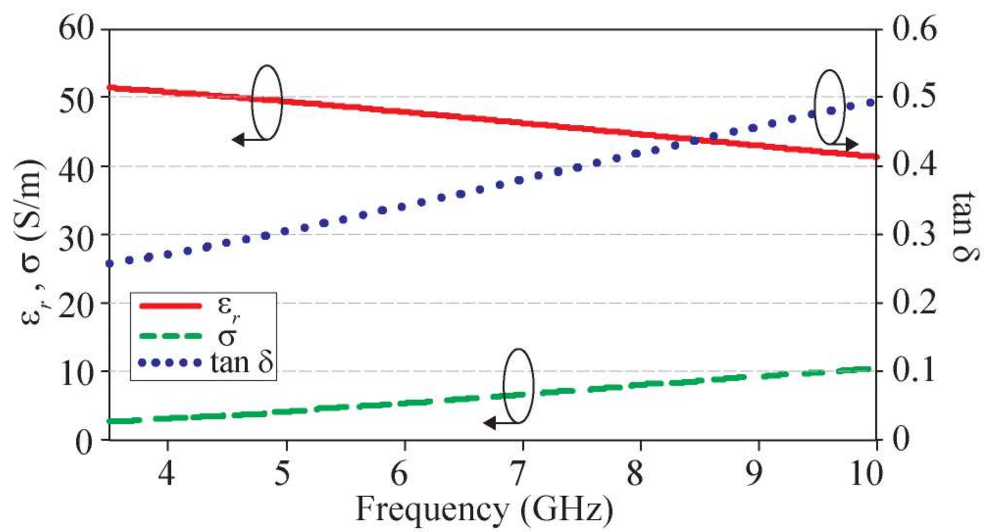
Simplified body phantoms for simulation



Proposed for body-worn textile antenna

The proposed antenna on top of a frequency dependent homogeneous human muscle equivalent phantom: rectangular (top) and cylindrical (bottom).

Two human muscle-equivalent phantoms were used to analyze the performance of the antenna in the presence of human body.

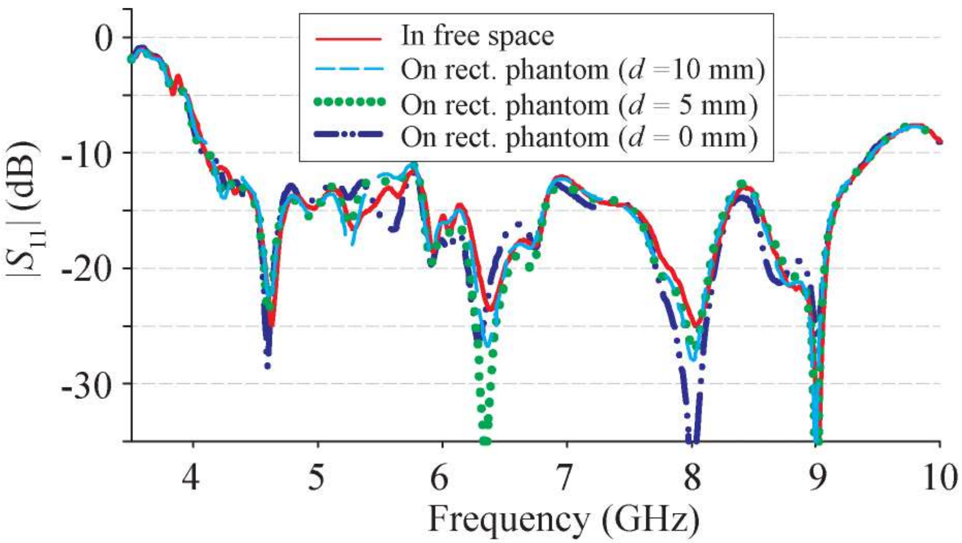


Characteristic of the phantom used in simulations based on Cole-Cole dispersive model.

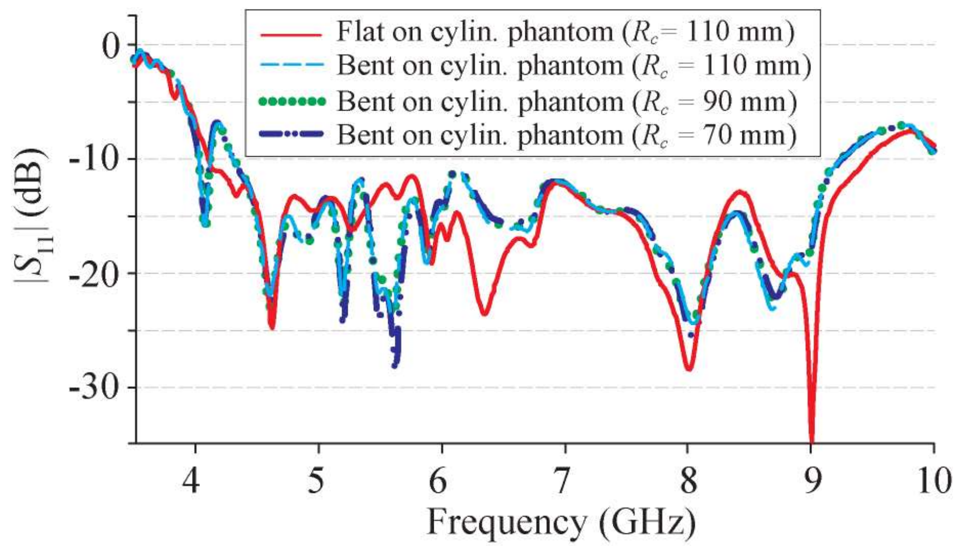
Results

Antenna input matching

Predicted $|S_{11}|$ of the proposed antenna in free space and with the phantoms.



Predicted $|S_{11}|$ of the proposed antenna with different separation gaps from the phantoms.



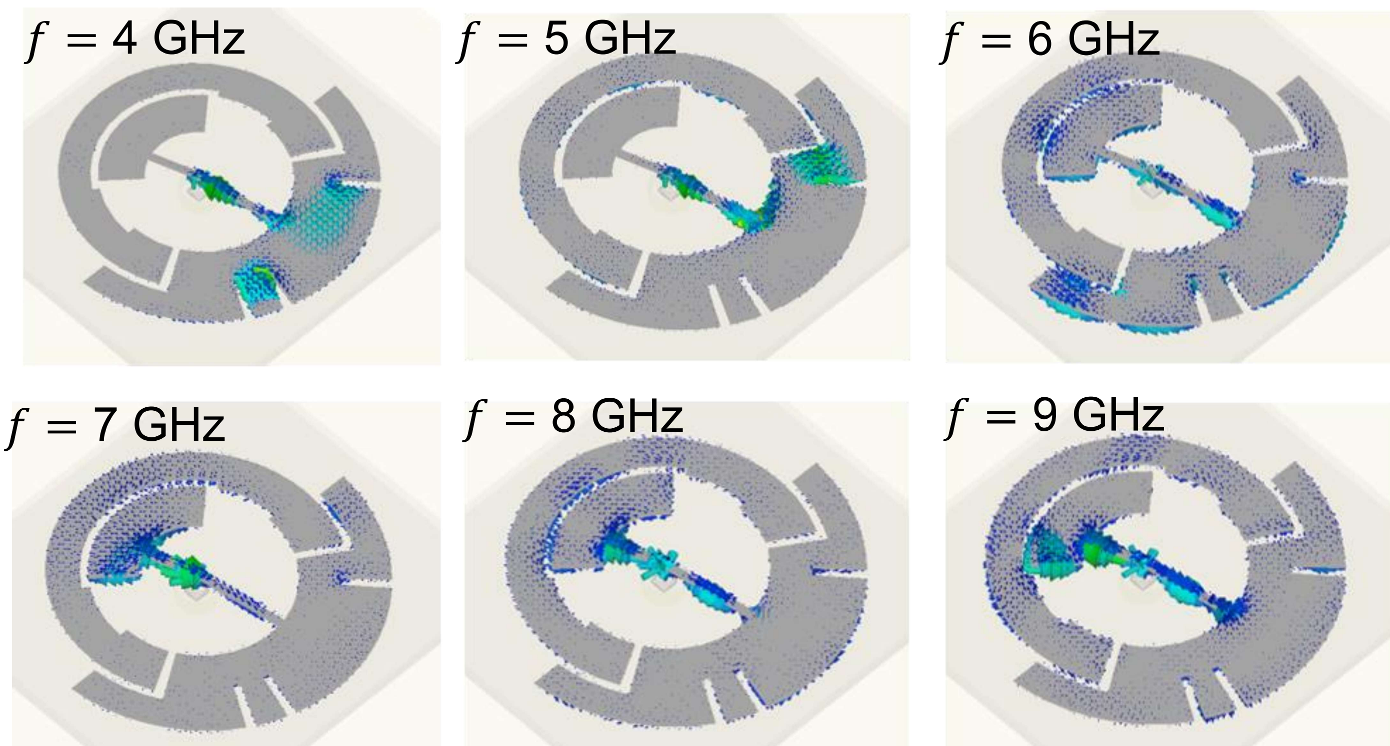
Predicted $|S_{11}|$ of the proposed antenna with various curvature radii of the phantoms (d = 10mm).

A robust input impedance is maintained. Bandwidth:

- In free space & on rect. phantom: 4 – 9.5 GHz (FBW: 81.5%)
- On cylindrical phantom: 4.2 – 9.3 GHz (FBW: 75.6%)

Results

Antenna surface current distribution

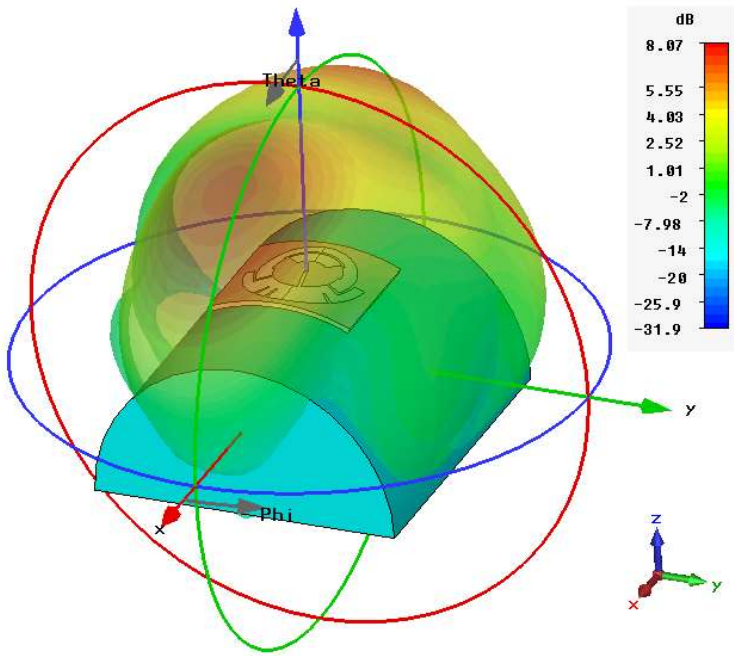


Surface current distribution of the proposed antenna.

- **Smaller and bigger arc-shaped patches**: operate at higher and lower bands.
- **Three slots** (each $l < \lambda_g/4$): extend the lower band.
- **Arc-shaped parasitic patch**: improves matching throughout the bandwidth

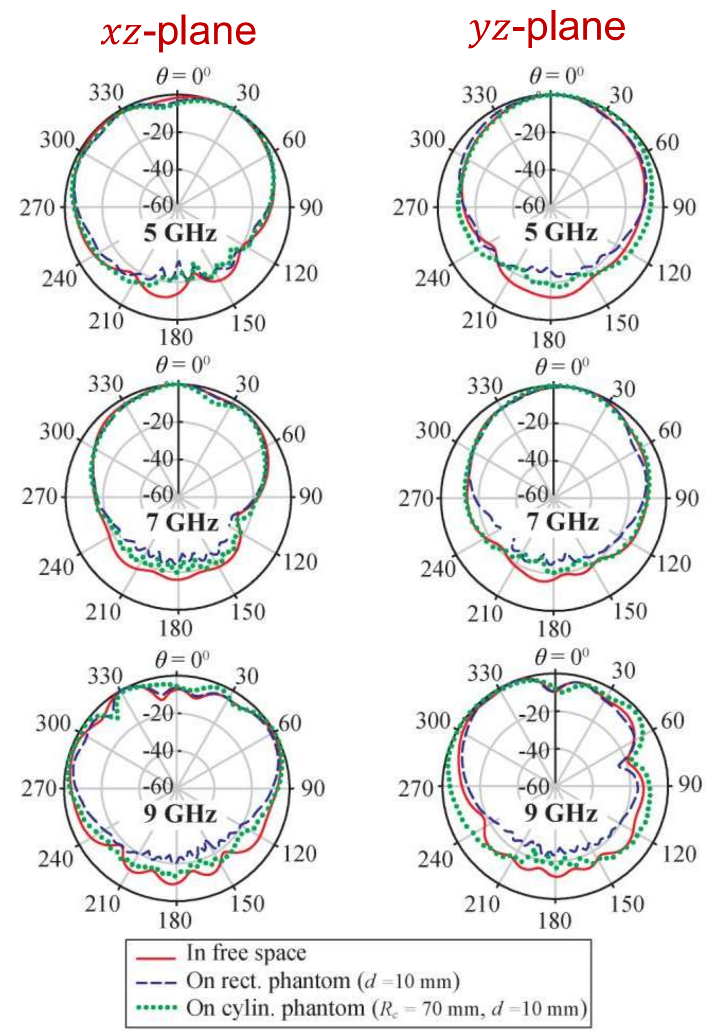
Results

Antenna radiation patterns



3D radiation pattern of the proposed antenna at 5GHz when placed on the cylin. phantom.

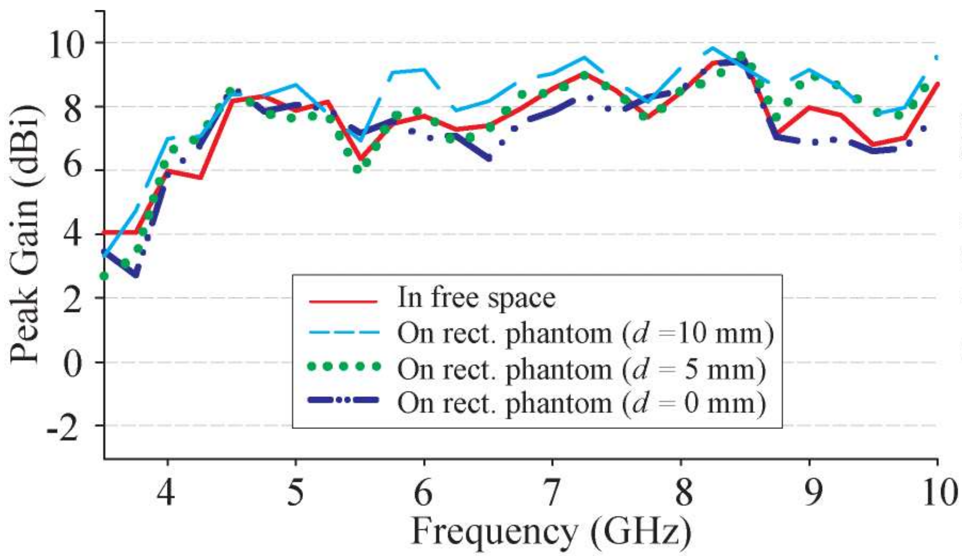
Radiation towards normal direction of the antenna is suitable for **OFF-BODY** communications.



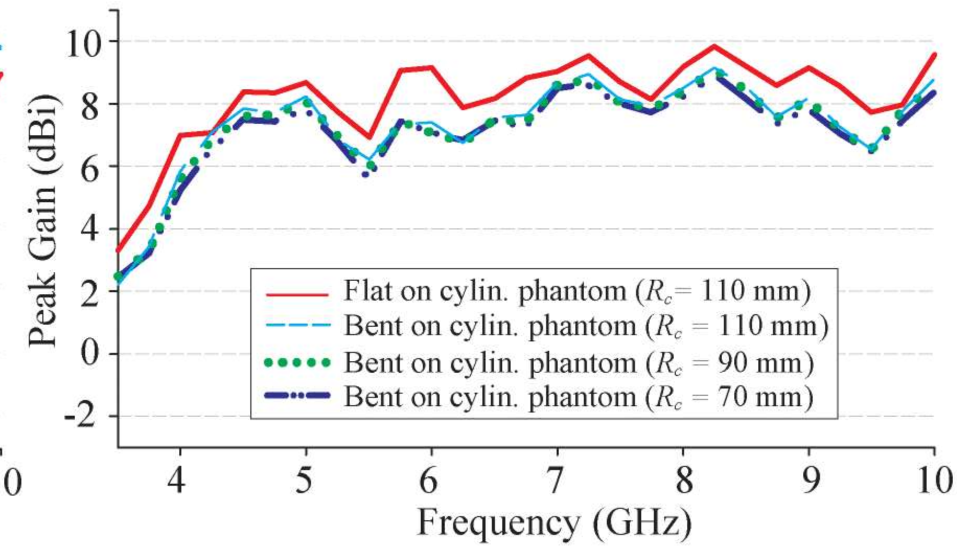
Normalized predicted radiation pattern of the proposed antenna in the *xz*-plane (left row) and *yz*-plane (right row).

Results

Antenna gain and efficiency



Predicted peak gain of the proposed antenna with different separation gaps from the phantoms.



Predicted peak gain of the proposed antenna with various curvature radius of the phantoms (d = 10mm).

- **Average gain**: **7.9 dBi** (in free space); **7.7 dBi** (10 mm above rect. phantom); **7.4 dBi** (10 mm above cylind. phantom)
- **Average tot. efficiency**: **92.3%** (in free space); **~85%** (10 mm above rect. or cylind. phantom)

Results

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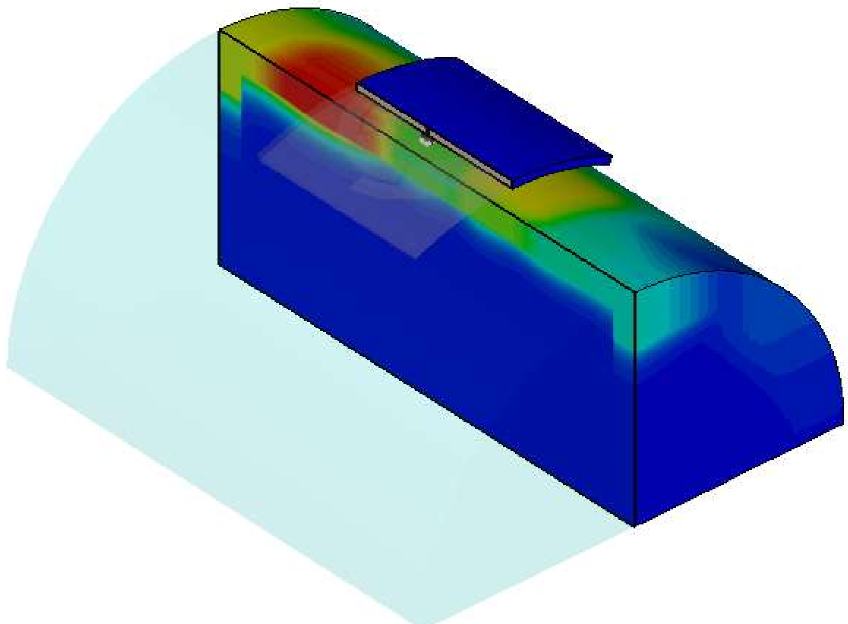
Peak 10gr averaged Specific Absorption Rate (SAR), input power $P = 0.5$W



COMPUTED MAXIMUM 10 G AVERAGED SAR VALUES ($d = 10$ MM, $R_c = 110$ MM, POWER = 0.5 W)

Frequency	Max. SAR [W/kg]	
	On rect. phantom	On. cylin. phantom
5 GHz	0.141	0.196
7 GHz	0.0865	0.0957
9 GHz	0.185	0.225

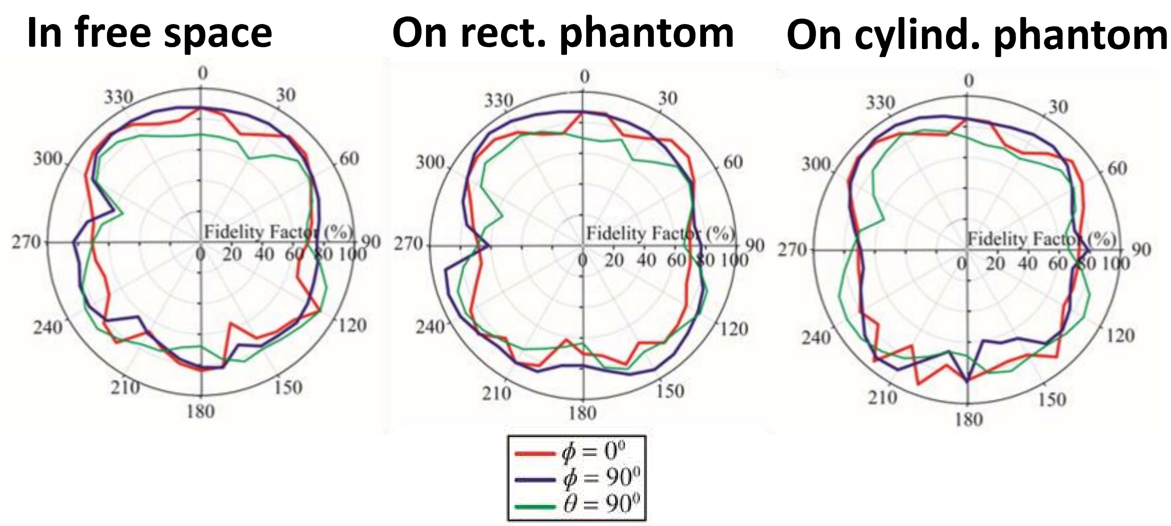
Predicted 10gr averaged SAR of the antenna placed on top of the phantom.

The peak SAR values are **below the IEEE C95.1-2005 standard** **(2W/kg averaged over 10 g of tissue)**

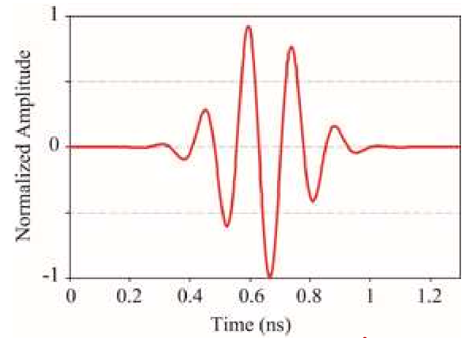
Results

Transient characteristics: Fidelity factor

Fidelity factor: the absolute value of the peak cross correlation function, a **measure of similarity** of input and radiated pulses.

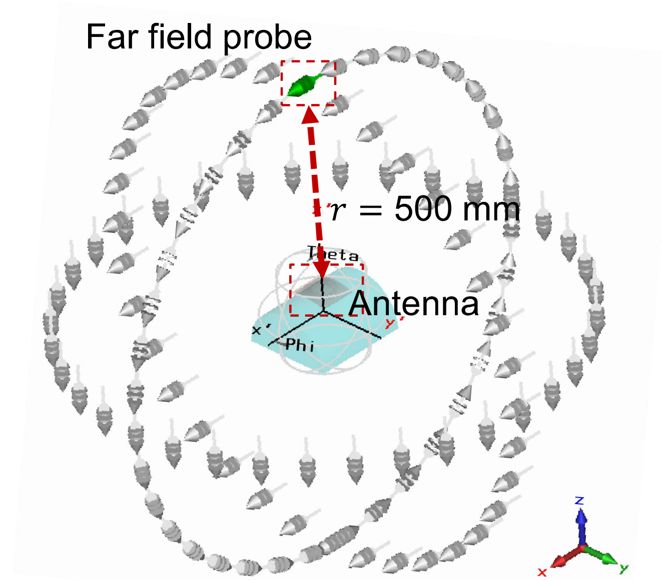


Predicted fidelity factor of the proposed antenna in three different planes.



Spectrum corresponding to 4 – 9.5GHz

Input signal: CST default Gaussian modulated pulse.



Far field probe placement in 3 different planes for fidelity factor computation in CST.

The fidelity values (in free space and on the phantoms) have an average of **more than 76%** in each plane which is higher than the commonly accepted **minimum of 50%.**

Conclusion

- Conventional printed UWB antennas are bi-directional. When placed on body for off-body communications, significant amount of energy is unnecessarily absorbed by the body due to the lack of full ground plane.
- New UWB printed antennas are suitable for off-body communications because their full ground plane isolates the antenna from the human body.
- Even in a very close proximity to a cylindrical phantom (d=10mm), a bandwidth of **75%**, an average gain of **~7.4 dBi**, an average total efficiency of **~85%** and an average fidelity **>76%** are achieved.
- Their robust characteristics against human body loading and structural deformation make them a suitable candidate for **UWB body-worn textile antennas integrated into garments**.